The Optically Pumped Cs Frequency Standard at the NRLM

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ABSTRACT

The optically pumped Cs frequency standard is being developed at the NRLM, and the construction is almost finished. Its microwave cavity length is 0.96m, and the dimensions are almost the same as the conventional type frequency standards at the NRLM. Light sources for optical pumping and detection, whose frequencies are stabilized by means of saturated absorption spectra of Cs, are also developed.

Using this apparatus, we could observe Ramsey resonance signal and could confirm the two frequency pumping effect. In addition, pumping with σ^+ polarized laser light, we also confirmed that the magnetic field could be measured using Zeeman coils in the same way of conventional type.

1. Introduction

Since an optically pumped Cs frequency standard using laser diodes was proposed[1], basic experiments were carried out[2,3,4,5] and frequency standards based on this new method are being realized at several laboratories. At the National Research Laboratory of Metrology (NRLM), the development of this type of standard aiming a primary frequency standard was started in 1984. Its dimensions are made to be almost the same as the NRLM-II and the NRLM-III (this is also a newly developed conventional type standard) for the purpose of comparing both types. The other conditions, for example; the degree of vacuum, magnetic shields, etc., are also almost the same.

As the construction was almost finished, some preliminary experiments were carried out to confirm the fundamental functions of this standard and to find out the problems of the apparatus.

This paper describes the construction of the optically pumped Cs frequency standard developed at the NRLM using photographs and some results of the preliminary experiments.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **DEC 1987**	2. REPORT TYPE	3. DATES COVERED **00-00-1987 to 00-00-1987**

4. TITLE AND SUBTITLE **The Optically Pumped Cs Frequency Standard at the NRLM**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **National Research Laboratory of Metrology,1-1-4, Umezono, Tukuba-shi,Ibaraki 305 Japan,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Proceedings of the Nineteenth Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, Redondo Beach, CA, 1-3 Dec 1987

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

2. Apparatus

2.1 Atomic Beam Tube

Figure 1 shows the optically pumped frequency standard developed at the NRLM. The vacuum chamber is cylindrical, and its length is about 2.5m and diameter is about 400mmϕ. This chamber can be separated into one central chamber and two side chambers. Each of the side chambers contains a Cs oven and its sliding mechanism to adjust the position of the oven. Two ion-pumps are attached and 10^{-6}Pa is kept. Four frequency stabilized laser light sources are mounted to the beam tube. There are eight windows which make it possible to put in the laser light parallel and perpendicular to the C-field direction. (C-field direction is perpendicular to the beam tube and parallel to the ground.) Then, the experiments of two frequency laser optical pumping[6] can be carried out with any combinations of laser light polarizations. The magnetic shield consists of three layer cylindrical permalloy cases.

Figure 2 shows the resonator. The microwave cavity length is 0.96m, and a Helmholtz coil for C-field generation and eight Zeeman coils for C-field measurement are mounted on several aluminum plates fixed to four phosphor bronze bars. The compensation coils to widen the uniform C-field region are placed at the both ends. Two pairs of photo-detecting system composed of photo-diodes and light collecting mirrors are placed at the both sides.

2.2 Frequency Stabilized Laser Light Source

A laser diode (LD) is mounted on a copper plate as shown in Fig.3. The laser temperature stabilization system consists of two stages to reduce the influence of the room temperature fluctuation, and both of them are constructed by a thermistor, a Peltier cooler and a PID controller. The temperature fluctuation of the copper plate which the laser diode is mounted is shown in Fig.4.

The spectral width of the laser diodes is 10~15MHz, then the hyperfine structure can be resolved but all the Zeeman sublevels are included in the laser spectral width.[7]

Figure 5 shows the frequency stabilized laser light source whose frequency is locked to the saturated absorption spectrum. The block diagram of this light source is shown in Fig.6. The light put out from LD is linearly polarized and is split in two beams by a polarized beam splitter (PBS1). The intensity ratio of the two laser beams is adjusted by the rotation of the $\lambda/2$ wave plate. The reflected light is strong (usually several mW) and is used for optical pumping or detection, and its section is about 2mm×4mm. The transmitted light is weak (about 100μW) and is used for laser frequency stabilization. The saturated absorption spectrum superposed on the linear absorption spectrum is observed by the photo-diode (PD1), and the linear absorption

spectrum is observed by the PD2. Subtracting the signal of the PD2 from that of the PD1, we can obtain almost only the saturated absorption spectrum. We adopted this method[8] because it does not need a mechanical chopper and there is no mechanical vibration.

3. Preliminary Experiments

Conditions of this experiment are as follows. The Cs oven temperature is 120℃, C-field is 7.9A/m and the effective section of the Cs atomic beam is about 6mm× 4mm. (The beam section is the temporary one which is not designed for the optically pumped standard.) The degree of vacuum is 4×10^{-6}Pa and the room temperature is 23℃.

Laser light sources are used as follows.

Light source	Region	Frequency	Polarization	Incident Power
①	Pumping	F=4—F'=4	σ	~1.0mW
②	Pumping	F=3—F'=3	π	~0.6mW
③	Detection	F=4—F'=4	σ	~0.1mW

Where, F=4— F'=4 means the transition frequency between [$^2S_{1/2}$,F=4] and [$^2P_{3/2}$,F'=4], and σ-polization is linear polalized light whose incident direction is parallel to the C-field. The combination of ① and ② satisfies the condition of the two frequency optical pumping. Power is adjusted by neutral density filters. Those filters functioned as optical isolators and the incident power is mainly limited by the influence of the reflection light from the windows of the beam tube. This limitation is one of the problems which have to be improved.

Figure 7 is an example of the Rabi-Ramsey spectra obtained by sweeping the microwave frequency. We can recognize that almost all atoms gathered to the central Rabi-Ramsey spectrum owing to the two frequency optical pumping. The spectra of $m_F=\pm 1$ are remained slightly. Those spectra can be reduced by adjusting the crossing points of laser beams and Cs beam, which is important because the pulling by the neighboring spectra can be reduced and the uncertainties connected with C-field can be also reduced by weakening the C-field strength. The center frequency of the Ramsey resonance in the central spectrum corresponds to the clock frequency, and Fig.8 shows its enlarged spectrum. The SN ratio of this Ramsey spectrum is improved in comparison with the Ramsey spectrum by single frequency pumping using only the light source ①. The width of the spectrum shown in Fig.8 is about 110Hz, which is almost the same as the width of the spectrum by the single frequency optical pumping although the two frequency pumping needs higher power of laser. This means that the optical pumping is almost saturated. It is considered that the remained

noise in Fig.8 is mainly caused by the laser frequency fluctuation due to the reflected laser light from the beam tube windows.

The estimation of the C-field strength is very important for a primary frequency standard. In the conventional type standard, Zeeman coils are used for the estimation by measuring the Zeeman transition frequency of F=4:m_F=-4 and -3. The measurement of that transition is possible basically in the conventional type, but we have to adopt other method in the optically pumped standard. Then the method of the following procedure is adopted.

Pumping by a σ^+ polarized laser light stabilized to F=4-F'=5 spectrum, all Cs atoms in the energy level of F=4 are optically pumped to F=4:m_F=4 sublevel. Then those atoms are perturbed by Zeeman coils and the transitions to the other Zeeman sublevels are occurred, and those transitions are observed by the detection of the fluorescence light excited by other σ^+ polarized laser light also stabilized to F=4-F'=5 spectrum. The observed Zeeman spectrum contains mainly the transition between F=4:m_F=4 and m_F=3. Although the other $\Delta m_F = \pm 1$ transitions might be contained slightly, those are negligible for the C-field estimation. Figure 9 is an example of the obtained Zeeman spectra. The Zeeman transition can be observed with good SN ratio easily. The reason is that the light reflected from the vacuum chamber windows cannot return to the laser diodes in this experimental condition and the frequency stability of the laser diodes is not reduced. The σ^+ polarized light is produced by placing a $\lambda/4$ wave plate in front of the light source, and the combination of the $\lambda/4$ wave plate and PBS1 becomes an isolator.

4. Conclusions

The construction of the optically pumped Cs frequency standard is almost finished, and we could carry out some preliminary experiments. Ramsey resonance and Zeeman transition were observed, and the prospect of the success of the development was obtained.

The laser power of about 1mW is almost sufficient for the two frequency optical pumping. The intensity of the $m_F = \pm 1$ Rabi-Ramsey spectra is controllable by changing the crossing positions of the two laser beams and the Cs beam.

The reflection lights from the windows have to be reduced to improve the laser frequency stability and to decrease the stray light.

Acknowledgment:

The authors would like to thank Dr. M. Morimura and Dr. T. Ohishi for their encouragement and support.

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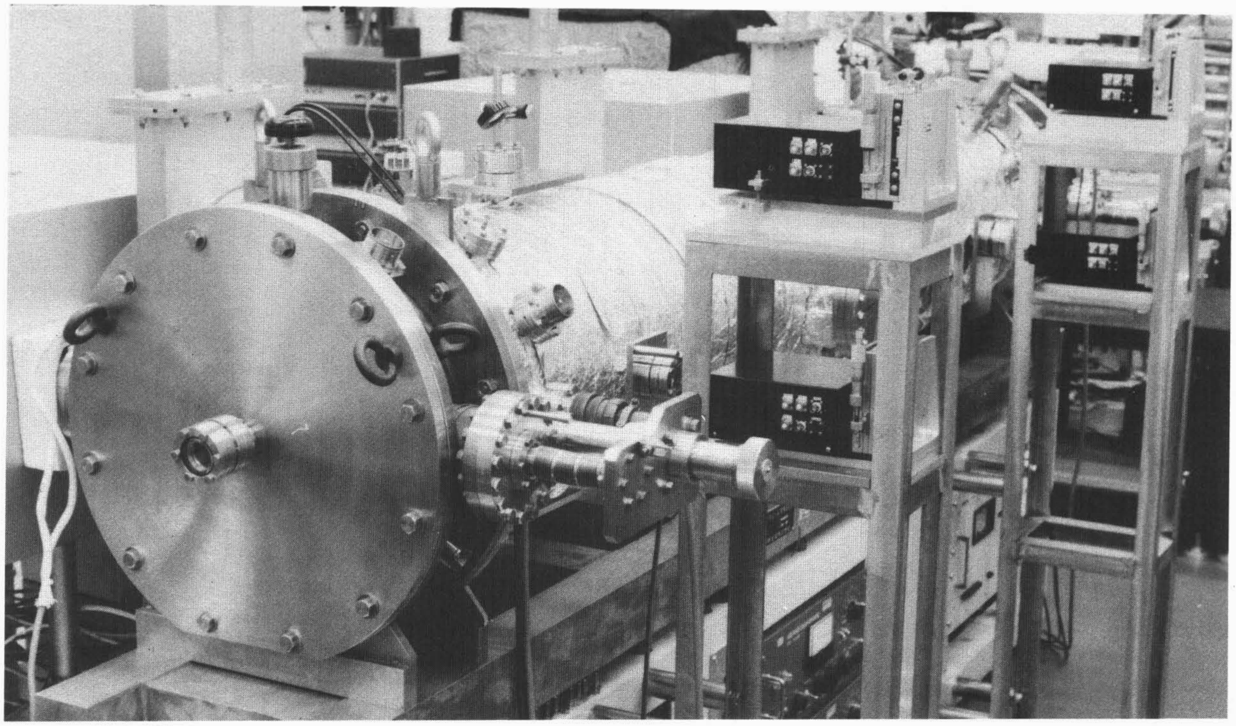

Fig.1 : Optically pumped Cs frequency standard developed at the NRLM.

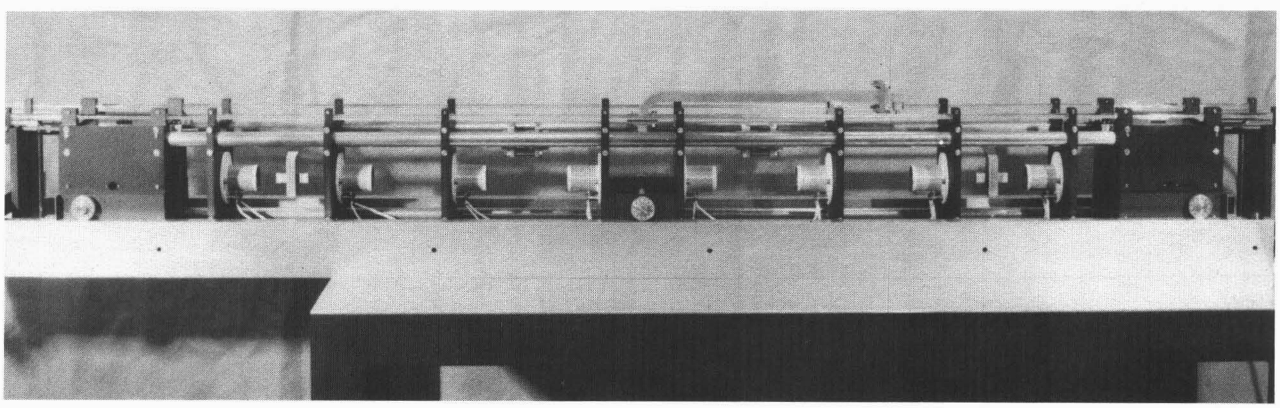

Fig.2 : Resonator of the Cs atomic beam tube.

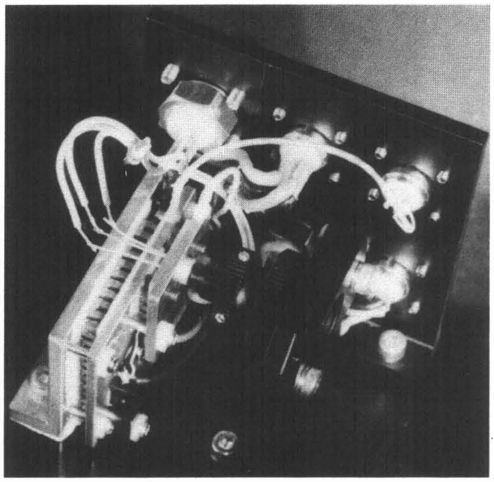

Fig.3 : Laser diode and its mount with a temperature stabilization system.

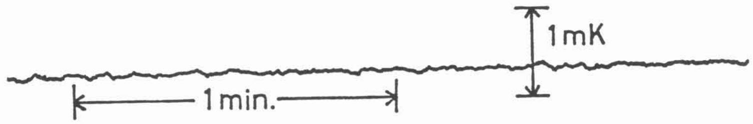

Fig.4 : Temperature fluctuation of the laser mount.

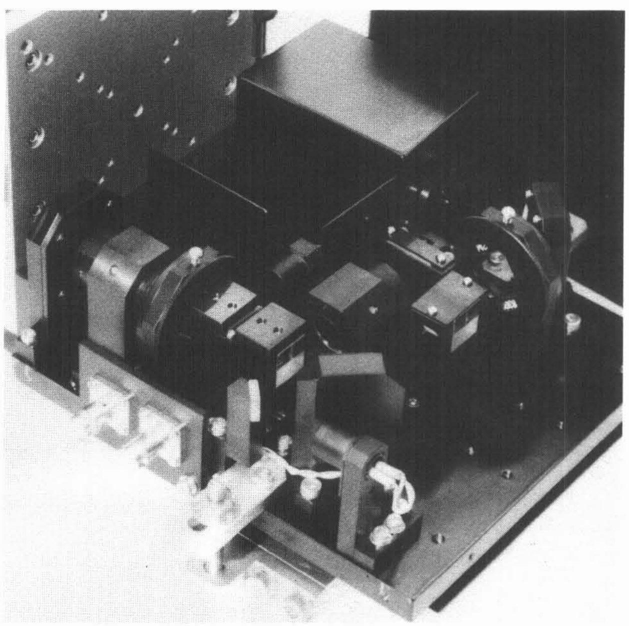

Fig.5 : Frequency stabilized laser light source.

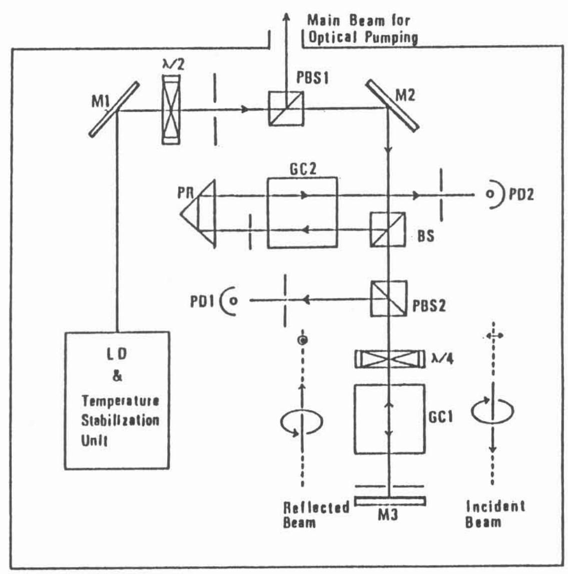

Fig.6 : Schematic diagram of the light source.

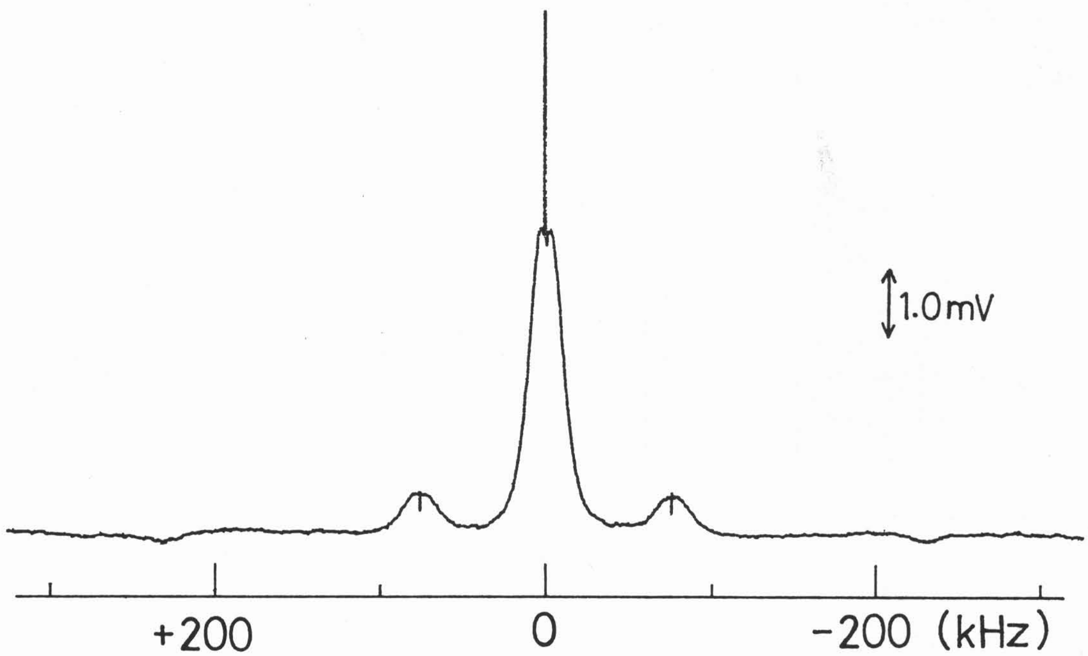

Fig.7 : Example of the Rabi-Ramsey resonance spectra obtained by two frequency optical pumping. ("0" means the clock transition frequency.)

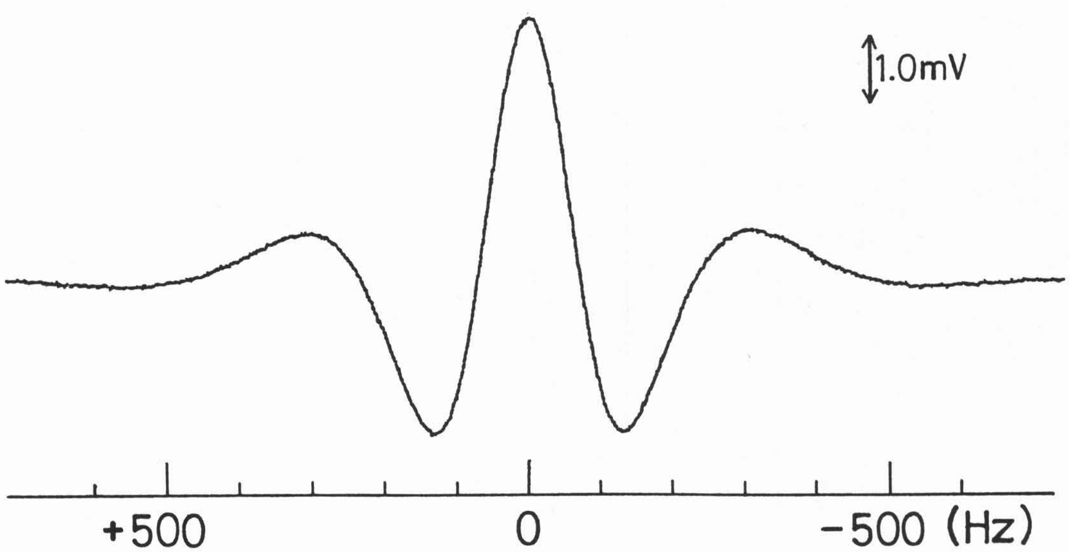

Fig.8 : Example of the Ramsey resonance spectrum. This spectrum is observed in the same condition of Fig.7 except the sweep width of the frequency.

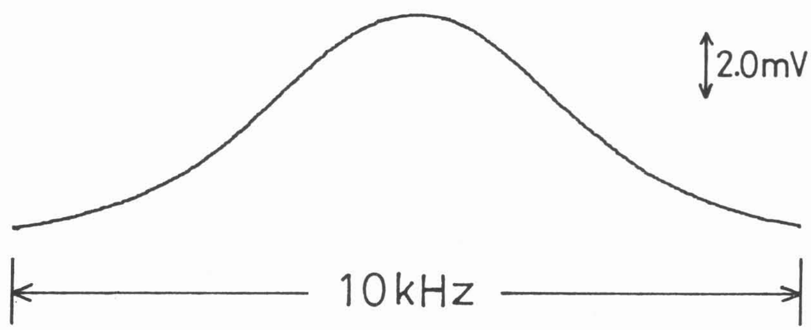

Fig.9 : Example of the Zeeman resonance spectrum.